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(58) Field of search
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(54) **Stators for electric motors**

(57) A multi-pole stator for an electric motor comprises a number of pole-pieces 1 with pole shoes 2 and a number of wedge pieces 5 between the pole pieces. Each of the pole pieces and wedge pieces is formed from a stack of ferro-magnetic laminations and the stator is assembled by inserting each of the pole pieces 1 through a coil, one of which is shown at 11, and then holding the pole pieces accurately in position by means of an electro-magnetic mandrel 13 having ridges 14 by which the pole shoes 2 are held at the required spacing. The wedge pieces 5 are then inserted. Owing to the tapering of the side faces of the pole pieces 1 and the end faces of the wedge pieces 5 there is satisfactory metal-to-metal contact between the wedge pieces 5 and the pole pieces 1 so that the magnetic flux path is not interrupted. The assembly of pole pieces and wedge pieces 5 is surrounded by an extruded aluminium tube 7 and the clearance space 9 is then filled with epoxy resin filler.

Fig. 1.

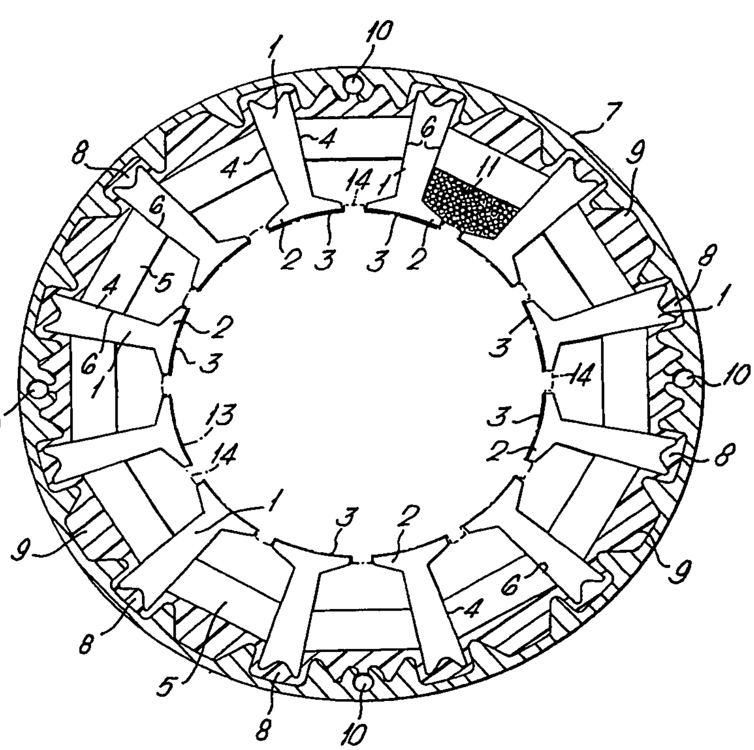

Fig. 1.

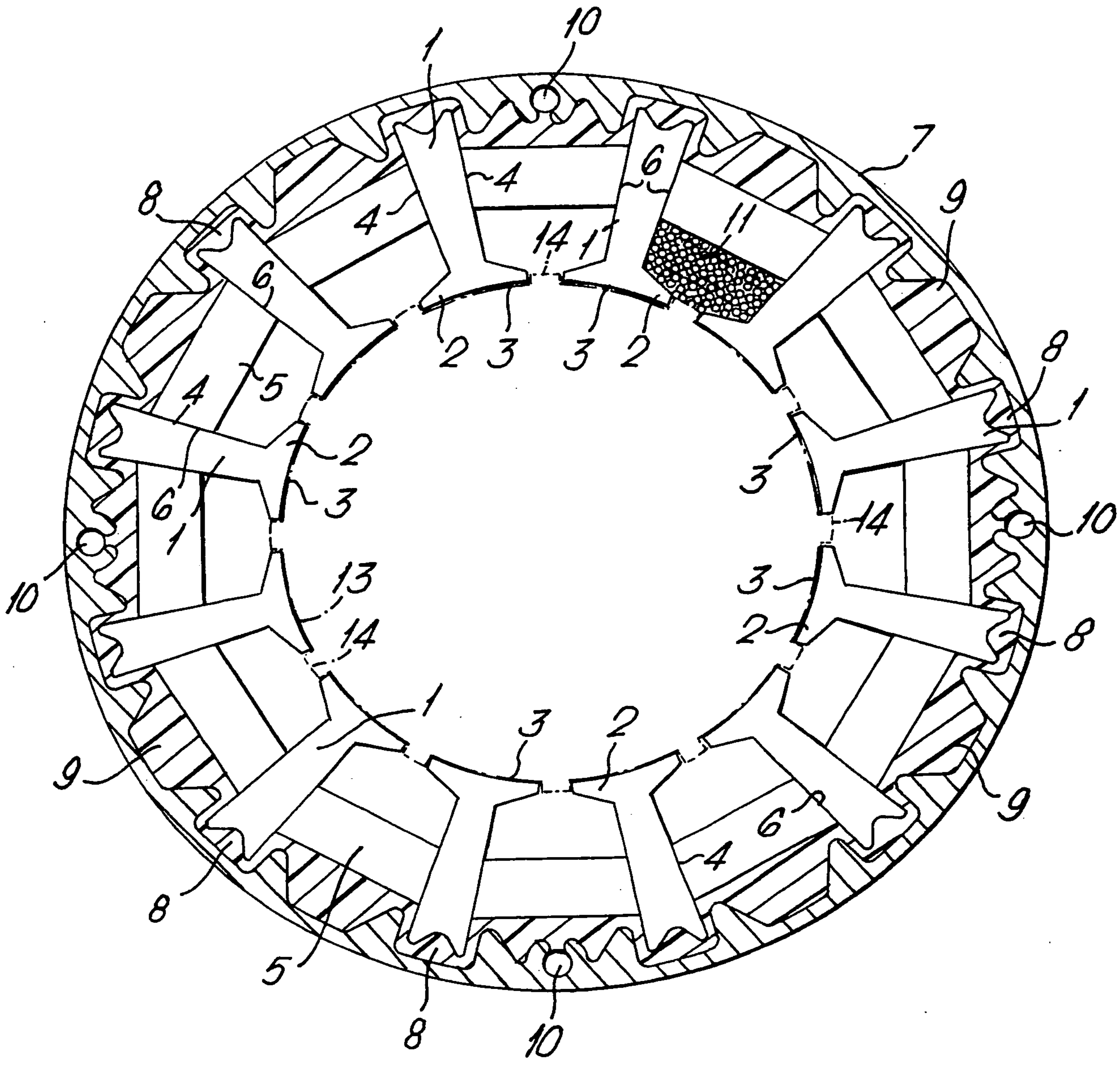
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Fig. 2.

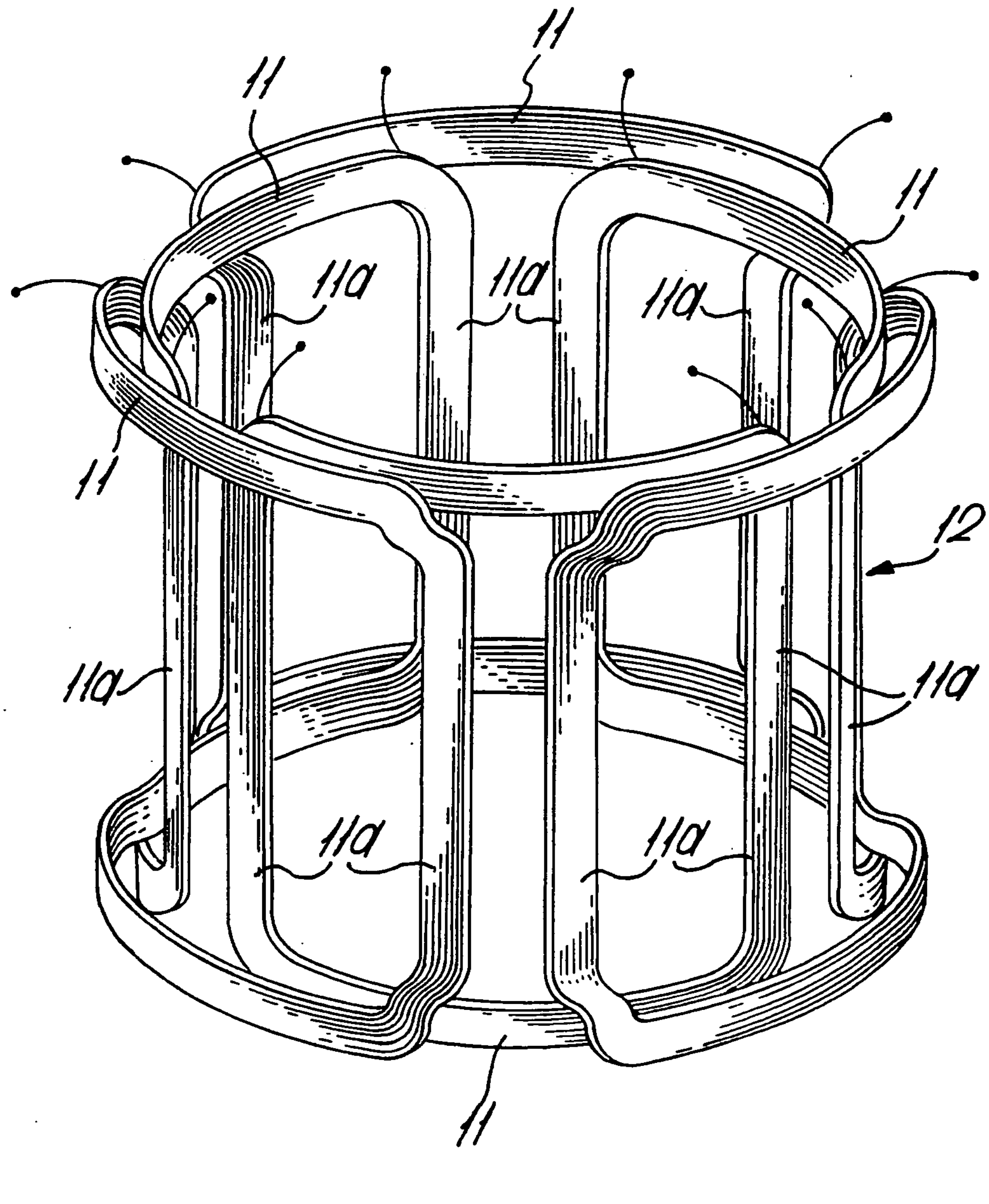
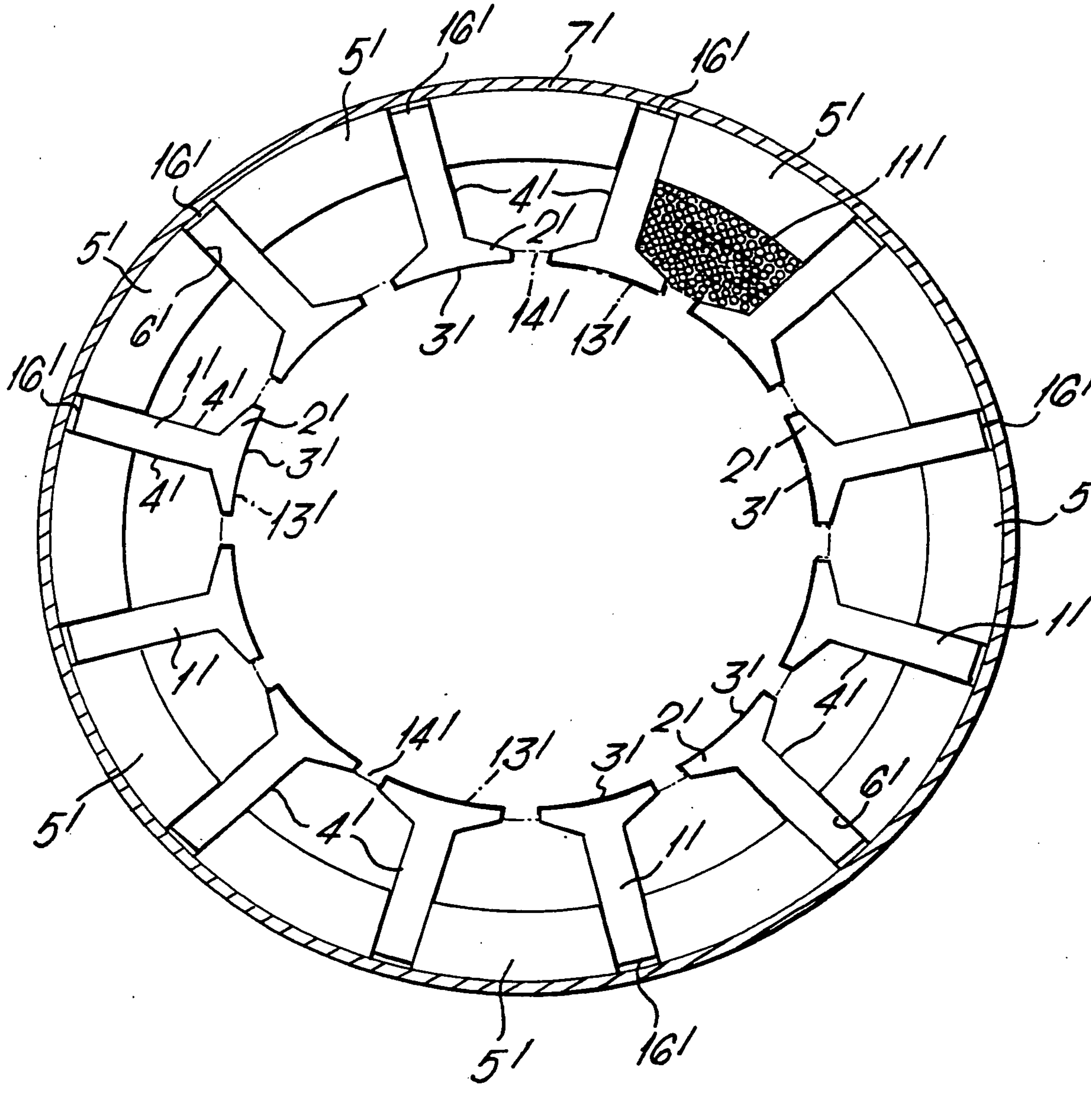


Fig. 3.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SPECIFICATION

Stators for electric motors

This invention relates to the manufacture of multi-pole stators for electric motors and it is particularly, but not exclusively, suitable for use in the manufacture of the stators of fractional horsepower motors and DC permanent magnet stepping motors.

The most usual method of making multi-pole stators for fractional horsepower electric motors consists in stamping out a series of ring-shaped laminations each of which has a number of portions forming parts of the pole-pieces of the stator and integral ring-shaped portions which form the magnetic flux path connecting together the pole-pieces. These laminations are then fixed together in a stack and either separate pre-formed coils are fitted over the pole-pieces, provided that the pole-pieces do not have pole shoes which prevent this being done, or the coils are wound in-situ on the pole pieces.

The stamping out of the laminations in the form of rings entails the waste of a great deal of the metal sheeting from which the laminations are formed and since this sheeting is commonly pre-coated with plastics material to insulate the laminations from each other, or both to insulate the laminations and to stick them together, the material which is wasted is expensive.

The aim of the present invention is to manufacture a stator primarily for a fractional horsepower electric motor comprising laminated pole-pieces in such a way that pre-formed windings may be fitted easily, the wastage of the ferromagnetic sheeting from which the laminations are formed is reduced and the flux path of the stator involves laminated members which are in direct metallic contact with the pole-pieces to avoid an increase of magnetic losses in the flux path so far as is practicable.

According to this invention, a multi-pole stator primarily for a fractional horsepower electric motor is made by a method which comprises forming an even number of pole-pieces each consisting of a stack of similar ferromagnetic laminations held together so that opposite side edges of the laminations lie on flat planes, each pole-piece having a pole shoe whch is formed integrally from the laminations at one end of the pole-piece and which has a width greater than that of the adjacent part of the pole-piece and has a part-cylindrical end face; forming a number of wedge pieces each consisting of a stack of similar ferromagnetic laminations held together so that the end edges of the laminations, which taper, lie on flat planes; forming a stator winding consisting of a number of coils; inserting the pole-pieces into the coils so that the pole shoes are adjacent the coils; placing the pole shoes around and in contact with a cylindrical mandrel and clamping the pole shoes to the mandrel so that the pole-pieces are evenly spaced around and project radially outwardly from the mandrel and the side faces of adjacent pole-pieces are inclined towards each other in an inward radial direction at an angle wedge piece between ach adjacent pair of pole-pieces so that the flat end faces of the wedge pieces and the flat side faces of the pole-pieces are in intimate metallic contact with each other, and surrounding the pole-pieces and the wedge pieces with a rigid encasement to hold them together in a ring so that the wedge pieces and pole pieces form the magnetic flux path of the stator.

When a series of similar laminations are stamped out from a sheet of ferromagnetic material, even though all of the laminations are stamped out with the same tool, there may be very slight tolerances in the sizes of the laminations. Generally speaking the laminations which form the pole-pieces can be stamped out with sufficient accuracy to make the opposite side faces flat enough to provide good magnetic contact between these faces and the flat end faces of the wedge pieces. To ensure still more accurate flatness of the side faces of the pole-pieces, however, the side edges of the laminations which form the pole-pieces may taper. Then by stacking the laminations of both the pole-pieces and the wedge pieces, which necessarily have tapering end edges, in jigs with very accurately flat faces with which the side and end edges of the laminations forming the pole-pieces and the wedge pieces respectively come into contact, it is a simple matter to stack the laminations so that the side and end edges lie on very accurately flat planes as is most desirable. In this way it is possible to fit the end faces of the wedge pieces between the adjacent side faces of pairs of pole-pieces in such a way that even more intimate metal to metal contact is obtained between the laminations of the pole-pieces and of the wedge pieces over the whole end areas of the wedge pieces than if possible if the pole pieces are parallel-sided.

The laminations of both the pole-pieces and the wedge pieces may be made of uncoated iron sheeting and the laminations are then bolted or riveted together with insulating sheeting between the adjacent laminations, but preferably as is nowadays common, the laminations are stamped out of soft iron or other ferromagnetic sheeting which is coated with uncured synthetic resin adhesive which forms an electrically insulated covering. The laminations are then stacked together in their jigs, are clamped together and heated to cure the resin which then causes the laminations to be stuck firmly to each other to form solid sticklike members.

If the flat side faces of each pole-piece taper towards each other in a radially inward direction towards the pole shoes, this angle of taper must be less than the included angle between the centre lines of adjacent pole-pieces so that the adjac nt side faces of adjacent pole-pieces are inclined radially inwards towards each other; that is to say so that the spaces between adjacent pole-pieces taper in a radially inward direction to enable th wedge pieces to be inserted into these spaces from outside the ring of pole-pieces clamped against the mandrel.

Preferably the coils which form the stator winding are fixed tog ther side by side in a ring with their central openings directed radially so that this assem-

of the ring-like cage and the mandrel is then inserted between the pole shoes which are held in position to some extent by the ring-like cage formed by the coils.

The mandrel preferably has longitudinally extending ridges between which the pole shoes fit so that the ridges set the positions and widths of the gaps between the pole shoes. The method has the great advantage that these gaps can be set to the optimum required from electro-magnetic considerations alone and it is not necessary as happens with some other forms of construction to make the gaps very narrow or non-existent to satisfy structural requirements or to make them over-wide to allow for the insertion of coil windings.

Preferably the mandrel is provided with an electro-magnetic core and the pole shoes are clamped to the mandrel by energisation of the electro-magnetic core. When the mandrel is made electro-magnetic in this way, the field generated by its core can also be used to assist in holding the wedge pieces in position between the pole pieces while the rigid encasement is being formed around the pole-pieces and the wedge pieces to hold them together in a single rigid ring.

Preferably the encasement consists of an aluminium tube which surrounds the outer ends of the pole-pieces and the outer sides of the wedge pieces. The side faces of the wedge pieces may be made proud of the outer ends of the pole pieces and in this case the aluminium tube may be shrink fitted so that it clamps the wedge pieces in position. Alternatively the outer ends of the pole pieces may project radially beyond the outer sides of the wedge pieces and, when this is the case, after the aluminium tube has been placed in position, one end of the tube is temporarily closed and the clearance space between the tube and the outside surfaces of the pole-pieces and wedge pieces is filled with a filling material which is initially fluid, but which subsequently sets rigid. This filling material must of course be both non-magnetic and electrically non-conducting and it is preferably an epoxy resin. The epoxy resin bonds the pole-pieces, the wedge pieces and the surrounding tube very rigidly together.

The stator may be completed by end caps which fit over the ends of the aluminium tube and are held together by axially extending bolts provided with nuts or by means of screws secured into slots in the aluminium tube.

It is not essential to ensure that the laminations in the pole-pieces lie in exactly the same planes as the laminations in the wedge pieces as, even if one lamination in a wedge piece spans the insulation between two adjacent laminations in a pole-pi ce, the eddy currents produced will cause only very minor losses.

Two examples of stators made by the method in accordanc with the invention are illustrated in the accompanying drawings, in which:-

Figure 1 is a somewhat diagrammatic cross-section through one example;

Figure 2 is a diagrammatic sketch to a smaller

Figure 3 is a cross-section similar to Figure 1, but of a second example.

In the first example shown in Figure 1, the stator comprises a number of pole-pieces 1, each formed by a stack of laminations each of which lies in a plane parallel to that of the paper. Each pole-piece 1 has a pole shoe 2 with a part-cylindrical surface 3 at its radially inner end. Each pole-piece 1 has side faces 4 which taper in a radially inward direction towards the pole shoes 2.

Between each adjacent pair of pole-pieces 1 is a wedge piece 5 formed from a stack of an equal number of laminations to those in the pole-pieces 1. The wedge pieces 5 have flat end faces 6 which taper in a radially inward direction and are in contact over their whole area with the flat side faces 4 of the pole-pieces.

The assembly formed by the pole-pieces 1 and the wedge pieces 5 is surrounded by an extruded aluminium tube 7 which has a complex internal profile which includes recesses 8 for receiving the outer ends of the pole-pieces 1.

The clearance between the internal surface of the tube 7 and the pole-pieces 1 and the wedge pieces 5 is filled with epoxy resin filler 9. Longitudinally extending channels 10 in the tube 9 are however left free of resin and form bores for receiving bolts or self-tapping screws which extend between and hold in position end caps which extend over the ends of the tube 7 and over the ends of the pole-pieces 4 and the wedge pieces 5.

Each of the pole-pieces 1 is surrounded by a coil 11, only adjacent parts of two which are shown in Figure 1. As shown in Figure 2, an assembly of a number of coils 11 equal to half the number of pole-pieces are connected to each other to form a ring-like cage 12 and the pole-pieces 1 are subsequently fitted one into each gap between adjacent axially extending limbs 11*a* of the coils.

In this example, the laminations of which both the pole pieces 1 and the wedge pieces 5 are made consist of soft iron sheeting which is coated with uncured heat-setting synthetic resin adhesive which forms an electrically insulating covering. Both the pole pieces 1 and the wedge pieces 5 are formed by stacking the required nunber of laminations jigs. The jig in which the pole pieces 1 are formed has accurately flat faces with which the side edges of the laminations engage to form the flat side faces 4. The jig in which the wedge pieces 5 are stacked has accurately flat faces with which the end edges of the laminations engage and form the flat end faces 6. With both the pole pieces and the wedges pieces, while the stacks of laminations are held in the jigs, they are heated to cure the resin adhesive and so fix the laminations to each other.

After the pole pieces have been inserted through overlapping coils 11 from the inside of the cage 12 as already d scribed, an electro-magn tic mandrel 13, which, is indicated in chain-dotted lines in Figure 1, is inserted into the cylindrical space bounded by the surfaces 3 of the pole shoes 2. The mandrel 13 has a series of longitudinally extending ridges 14 between

de-energised state and then it is energised. When energised, the pole shoes 2 are clamped to the mandrel and are held by the ridges 14 in accurately spaced circumferential positions.

While the pole shoes 2 and hence the pole-pieces 1 are held in position in this way, the wedge pieces 5 are inserted between the pole pieces with the flat end faces 6 in contact with the flat side faces 4 of the pole pieces. The magnetic field produced by the electro-magnetic mandrel 13 draws the wedge pieces 5 radially inwards and holds them in position.

While the assembly of the pole pieces 1 with the coils 11 surrounding them and the wedge pieces 5 are held in this way, the extruded aluminium tube 7 is placed around the assembly and the clearance between the internal surface of the tube 7 and the pole pieces 1 and the wedge pieces 5 is filled with the epoxy resin filler 9. When the epoxy resin filler has hardened sufficiently, the electro-magnetic mandrel 13 is de-energised and withdrawn.

Finally, to complete the stator, end caps are fitted and are fixed in position by bolts in the manner already described.

The second example shown in Figure 3 of the drawings comprises pole pieces 1′ with pole shoes 2′ having part-cylindrical faces 3′. Each pole piece 1′ is surrounded by a coil, parts two of which are shown at 11′. The coils 11′ are just the same as the coils 11 in the first example and are formed into a cage similar to the cage 12 shown in Figure 2. Between each adjacent pair of pole-pieces 1′ is a wedge piece 4′ with tapering end faces 6′, that is to say end faces which converge in a radially inward direction.

The pole-pieces 1′ and the wedge pieces 5′ are formed in exactly the same way as the pole pieces 1 and the wedge pieces 5 of the first example, but the differences from the first example are firstly that the side faces 4′ of the pole pieces 1′ are parallel to each other and secondly the external circumferential faces 15′ of the wedge pieces 5′ are proud of the outside end faces 16′ of the pole pieces 1′.

The pole pieces 1′ and the wedge pieces 5′ are formed in jigs in exactly the same way as the pole pieces 1 and the wedge pieces 5 of the first example, but because the side edges of the laminations from which the pole pieces are formed are parallel to each other, the side faces 4′ cannot be made quite so inaccurately flat as the side faces 4 in the first example. It is found, however, that the laminations can be stamped out sufficiently accurately for there to be very adequate metallic contact between the faces 4′ of the pole pieces 1′ and th faces 6′ of the wedge pieces 5′.

The pole pieces 1′ and the wedge pieces 5′ are assembled with each other in exactly the same way as the pole pieces 1 and the wedge pieces 5 of the first example by means of an electromagnetic mandrel 13′ with longitudinally extending ridges 14′.

However, after this assembly has been made, instead of fitting the aluminium tube 7 with a clearance which is subsequently filled with epoxy 5′. The shrink fitting of the tube 7′ clamps the wedge pieces 5′ very firmly in position between the pole pieces 1′ and it is this firm clamping which makes it possible to obtain adequate contact between the wedge pieces and the pole pieces without the faces 4′ being very accurately flat.

The clamping of the wedge pieces 5′ in position may, of course, be effected in ways other than shrink fitting the tube 7′. All that is necessary is to mak the tube 7′ a tight fit around the wedge pieces 5′ and this may be done, for example, by splitting the tube 7′ longitudinally and providing it with clamping bands, or by dividing the tube 7′ into two halves diametrically and providing both halves with axially extending flanges which are clamped to each other by bolts.

CLAIMS

1. A method of making a multi-pole stator for an electric motor, the method comprising forming an even number of pole-pieces each consisting of a stack of similar ferromagnetic laminations held together so that opposite side edges of the laminations lie on flat planes, each pole piece having a pole shoe which is formed integrally from the laminations at one end of the pole-piece and which has a width greater than that of the adjacent part of the pole-piece and has a part-cylindrical end face; forming a number of wedge pieces each consisting of a stack of similar ferromagnetic laminations held together so that the end edges of the laminations, which taper, lie on flat planes; forming a stator winding consisting of a number of coils; inserting the pole-pieces into the coils so that the pole shoes are adjacent the coils; placing the pole shoes around and in contact with a cylindrical mandrel and clamping the pole shoes to the mandrel so that the pole-pieces are evenly spaced around and project radially outwardly from the mandrel and the side faces of adjacent pole-pieces are inclined towards each other in an inward radial direction at an angle equal to the angle between the tapering end edges of the laminations of the wedge pieces; inserting a wedge piece between each adjacent pair of pole-pieces so that the flat end faces of the wedge pieces and the flat side faces of the pole-pieces are in intimate metallic contact with each other, and surrounding the pole-pieces and the wedge pieces with a rigid encasement to hold them together in a ring so that the wedge pieces and pole pieces form the magnetic flux path of the stator.

2. A method according to Claim 1, in which the side edges of the laminations which form the pole-pieces taper and the laminations which form the pole-pieces and the wedge pieces are stacked in jigs with very accurately flat faces with which the side and end edges of the laminations forming the pole-pieces and the wedge pieces respectively come into contact.

3. A method according to Claim 1 or Claim 2, in which the laminations which form the pole-pieces and the wedge pieces are stamped out of soft iron or

tions are clamped together and heated to cure the resin and stick adjacent laminations firmly to each other.

4. A method according to any one of the preceding Claims, in which the coils which form the stator windings are fixed together side by side in a ring to form a cage, the central openings of the coils being directed radially and one pole piece being inserted into the opening of each coil from the inside of the ring, after which the mandrel is inserted between the pole shoes.

5. A method according to any one of the preceding Claims, in which the mandrel has longitudinally extending ridges between which the pole shoes fit so that the ridges set the positions and widths of the gaps between the pole shoes.

6. A method according to any one of the preceding Claims, in which the mandrel has an electromagnetic core and the pole shoes are clamped to the mandrel by energisation of the electro-magnetic core.

7. A method according to any one of the preceding Claims, in which the encasement comprises an aluminium tube which surrounds the outer ends of the pole-pieces and the outer sides of the wedge pieces, the outer side faces being proud of the outer ends of the pole-pieces and the tube being shrink fitted so that it clamps the wedge pieces in position.

8. A method according to any one of Claims 1 to 6, in which the encasement comprises a tube which surrounds the outer ends of the pole-pieces and the outer sides of the wedge pieces and after the tube has been placed in position, one end of the tube is closed and a clearance space between the tube and the outside surfaces of the pole-pieces and the wedge pieces is filled with a filling material which is initially liquid, but which subsequently sets rigid.

9. A method according to Claim 8, in which the filling material is an epoxy resin.

10. A method according to Claim 1, substantially as described with reference to Figures 1 and 2, or Figure 3 of the accompanying drawings.

11. A stator for an electric motor made by a method in accordance with any one of the preceding Claims.

12. An electric motor incorporating a stator in accordance with Claim 11.

13. An electric motor according to Claim 12, which is a fractional horsepower motor.

14. An electric motor according to Claim 12, which is a DC permanent magnet stepping motor.

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(74) Agent and/or Address for Service
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(54) Reformed in place resilient retention springs

(57) Secure and rapid assembly of magnets (15, 16) or other articles in tubular or other-shaped housings (10) is achieved with bow type compression retainers (25) which are made from reformable spring metal, and are initially formed shorter and higher than their ultimate working dimensions to permit loose or easy manual or automatic assembly in their final working location, after which the retainers (25) can be reformed in place to a reduced height and extended length so as to take up any clearance and to place an initial load on abutting faces of the articles (15, 16) to be secured.

FIG. 1

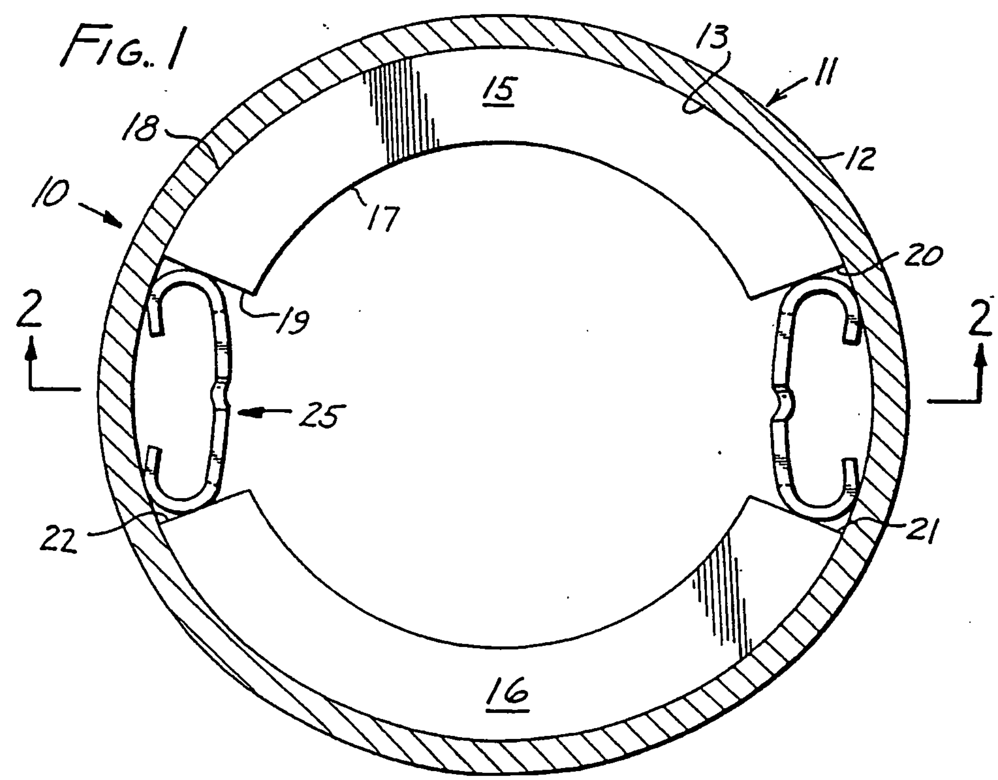

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FIG. 1

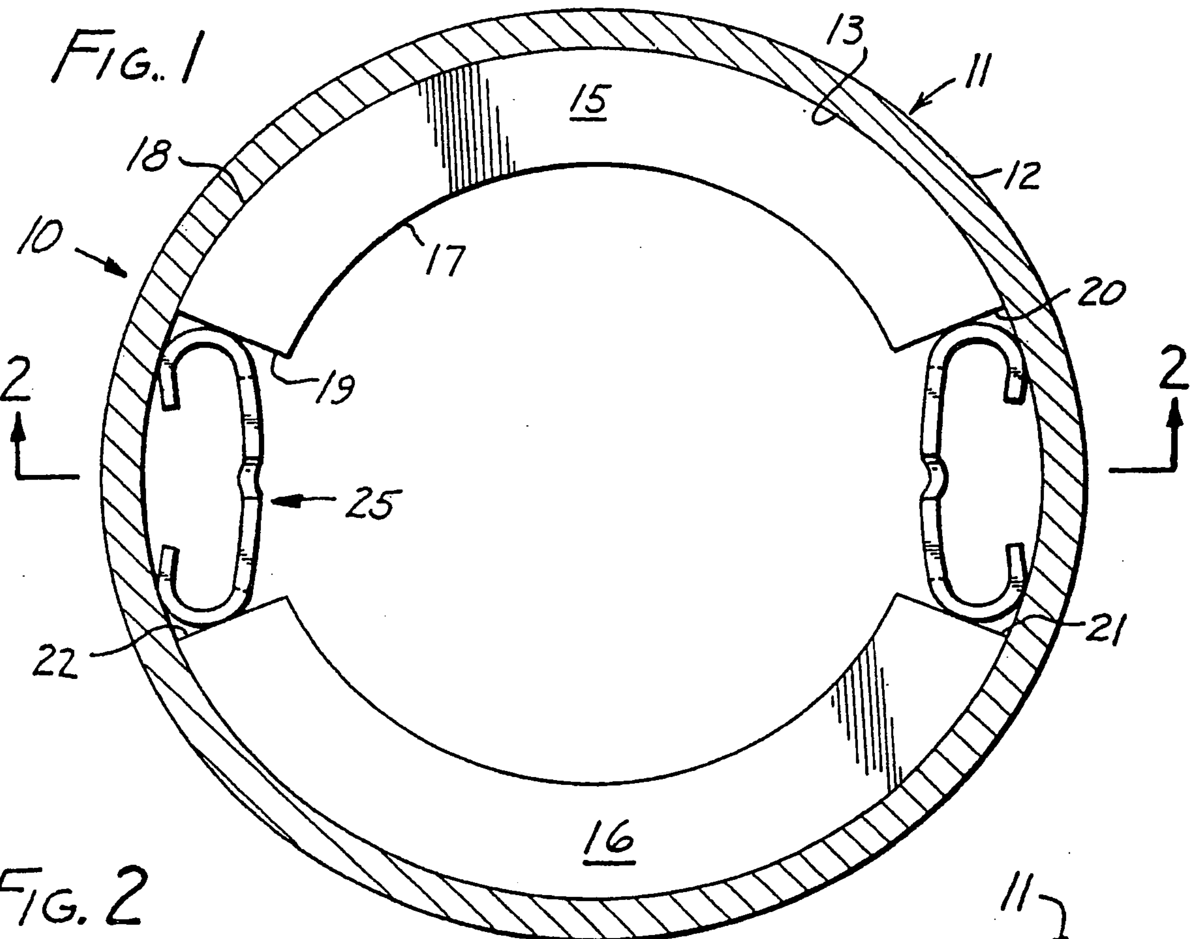

FIG. 2

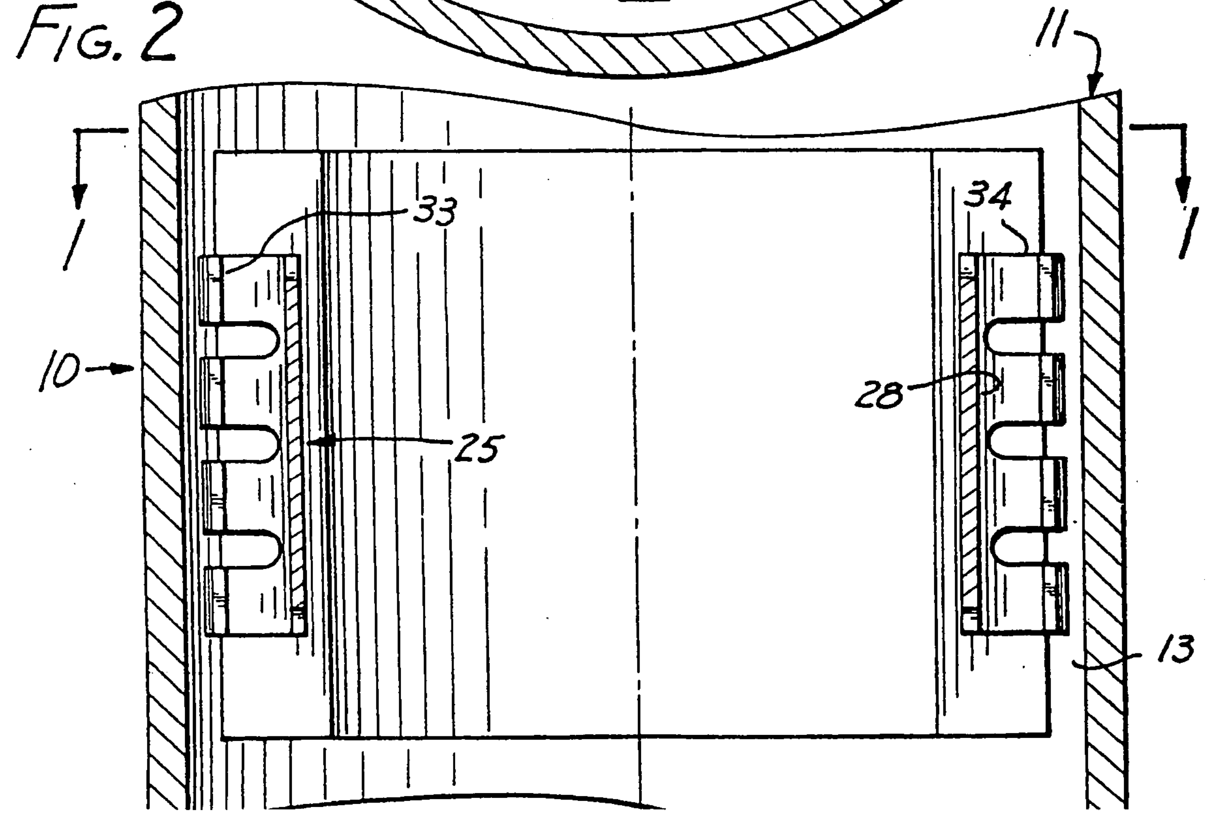

FIG. 3

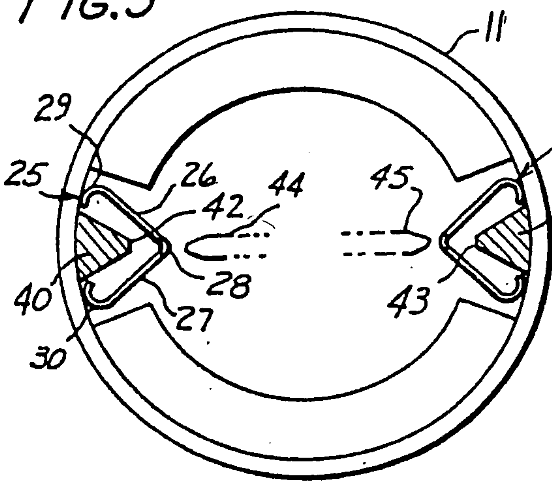

FIG. 4

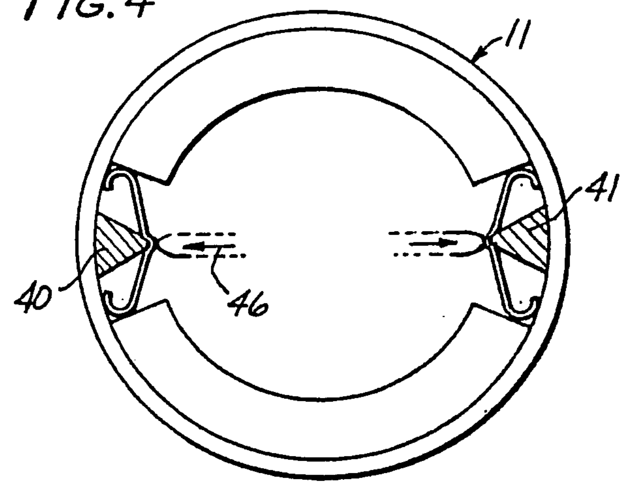

FIG. 5

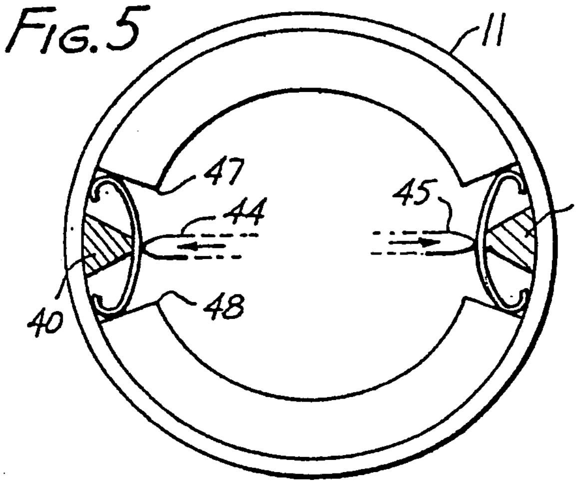

FIG. 6

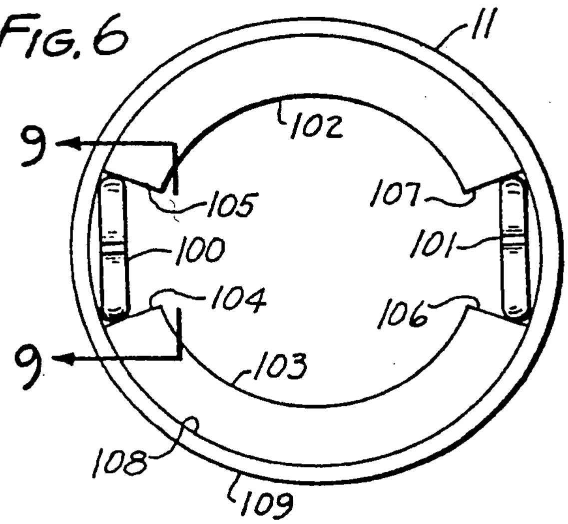

FIG. 7

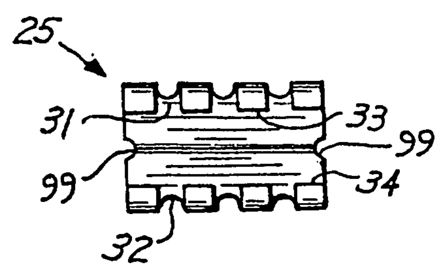

FIG. 8

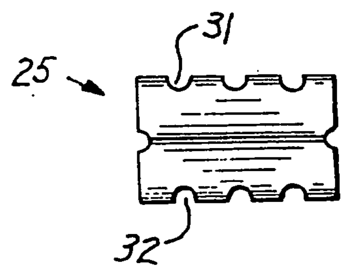

FIG.9

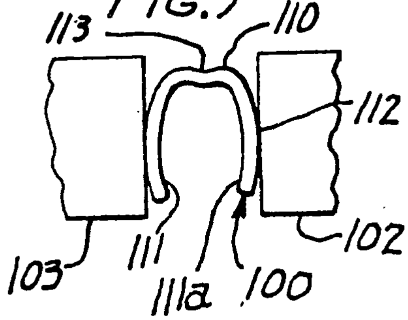

FIG.10

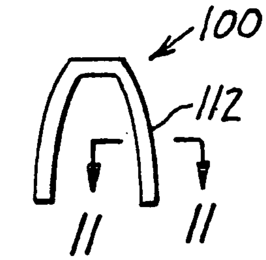

FIG.11

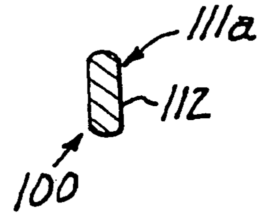

FIG.12

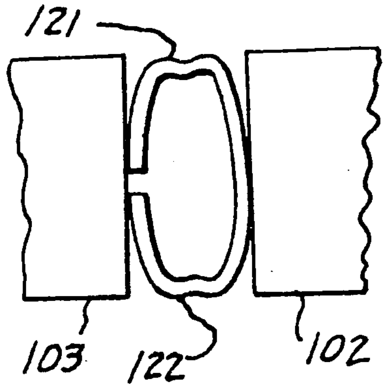

FIG.13

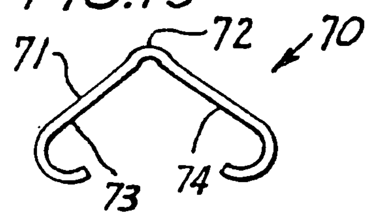

FIG.14

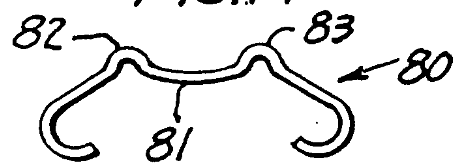

FIG.15

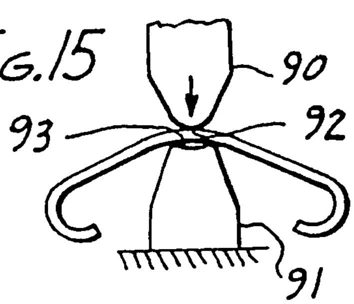

FIG.16

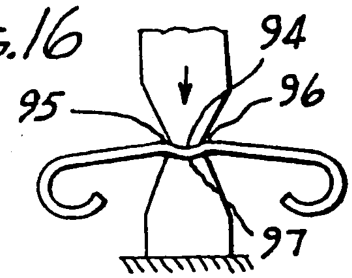

FIG. 17

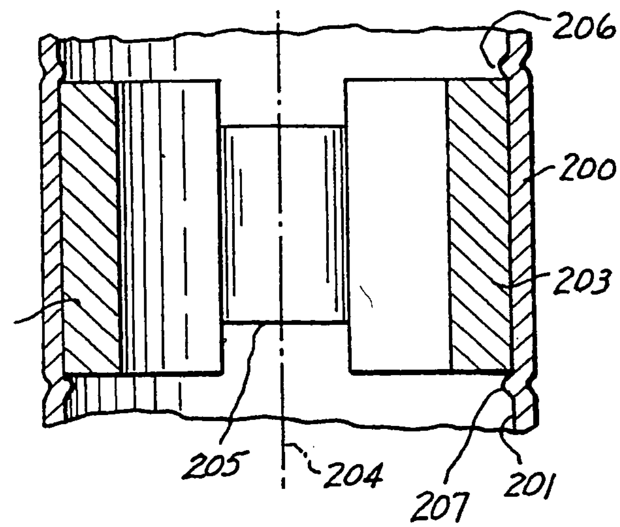
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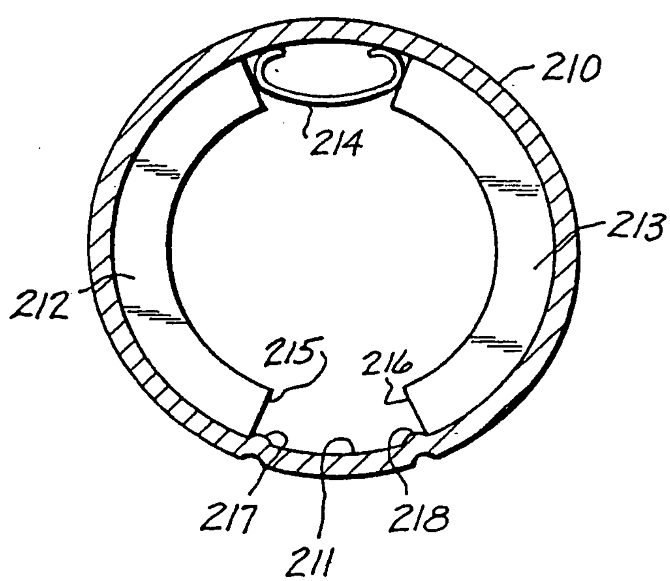
FIG. 18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SPECIFICATION

Reformed in place resilient retention springs

This invention relates to the spring retention of assemblies of articles, for example the retention of curved ceramic permanent magnets to the inside of a steel motor housing ring.

It is often desirable or necessary to retain equipment components without threading, piercing or otherwise re-working one of the components. Securing ceramic magnets in a steel housing ring for permanent magnet motors is one example. Spring retainer clips and adhesives are common means for accomplishing this objective.

Adhesive techniques and materials offer a wide variety of approaches for securing articles to one another. However, there are inherent disadvantages including the time required and the special equipment needed for curing the adhesive; the handling; mixing, applying and cleaning up of the adhesive; and precautions against noxious or toxic effects. Further, the costs of special quick-drying adhesives and related special equipment, and the troubles of maintaining the necessary tight control of surface tolerances are often significant. To avoid these, sometimes assemblies are secured with the use of both an adhesive and retainer clips.

The retainer clips may be removed after the adhesive has set, or they may be left in permanently, depending upon individual economic and structural considerations.

The use of spring retainers in lieu of adhesives is desirable, where practical. In some cases, the spring retainers — typically bow or wave-shaped flat metal compressing strings — are pressed or snapped into their final loaded position. In other applications the springs and magnets are assembled loosely in a larger diameter fixture, after which the assembly is compressed radially, and then axially inserted into the cylindrical housing.

There are a number of problems which limit the use and effectiveness of the existing spring retainer approaches. Variations in the arc lengths of the articles to be retained, and in dimensions of other mating components, pose difficulties with respect to critical relationships between the retainer spring's relatively short length, and the requirements for both sizable loads and large tolerance take-up capabilities. Closer control of tolerances entails higher costs. Also, the pre-compression, as well as the snap-in assembly operations often tend to break or chip ceramic magnets or other brittle articles. In some instances, spring retention systems have been avoided and even abandoned because of concern for unacceptable breakage, or for displacement from impacts during assembly, handling, shipping or use.

The need remains for a basically improved mechanical retention system which is adaptable to:

b. providing sizable, and consistent holding forces without damaging magnets or other parts being retained; and

c. easy and rapid manual or automatic assembly techniques (without contending with spring loads during assembly of components).

This invention addresses the above and other related needs with a resilient retainer structure and system which is reformed-in-place, i.e., a production-quality retainer with its tolerance variations is inserted into a system that can have significant tolerance variations, and is reformed-in-place to a new configuration which takes up small or large tolerance clearances as needed and then exerts a retentive force that is substantially independent of the tolerance take-up, and that provides essentially all of the force available with the yield strength of the retainer structure.

According to this invention, the retention spring is initially formed into a bow or a wave-shaped structure, whose extremities are short of their ultimately-intended working length. This enables rapid and easy placement in what will be its final working position. Then with special in-place re-forming tools and techniques, the ends of the "bow" or "wave" form retention springs are extended first adaptively to take up assembly clearance and tolerance variations, and then reformed further to "load" it in place. Limited intermediate sections of the retention spring are then permanently re-worked and reformed at apex points above the line between the working contacts at ends of the arms of the spring. This final re-working is limited to a relatively small portion of the spring's free length. In this limited area or areas the metal is permanently bent in a direction tending to open the bow curvature and thus to increase the intrinsic length of the spring and the bow-end forces against the next assemblies.

In effect, the spring is first only partially fabricated. It is made to an assembly length appreciably shorter than its working length. Then it is loosely assembled with the other parts, and reconfigured and loaded in place by the above methods. This reduces the insignificance the classical "spring-back" effects which tend to prohibit effective in-place loading of resilient members.

Large tolerances take-up capabilities are inherent in the reform techniques of this invention, and they can be further extended in preferred embodiments. The apex reforming technique its lf can take up tolerances which are large in relation to the small working deflection lengths common in the comparatively short, stiff compression springs that are usually employed for assembly retention.

Beyond this, curved or "wave" type s gments at the ends of the spring can be configured so as to be compr ssed, and take a permanent set during the in-place, re-form operation, with the bow as a whole then taking its load-set during the final apex re-form process.

A preferred method for conveniently and

variations is to curve the ends of the retainer arms to promote metal curling as the arms are extended during an initial compression of the apex and spreading of the arms of the retainer. During this initial reforming and spreading of the loosely assembled bow or wave spring the pre-curled ends of the spring slide on adjacent surfaces, and then engage the next articles at restraint angles which facilitate further curling of the ends in place, until the apex of the bow structure is deflected to its approximate working height — just prior to the final function of reconfiguration loading by local reforming, as previously described.

Embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Fig. 1 is a cross section of the presently preferred embodiment of the invention taken at line 1—1 in Fig. 2;

Fig. 2 is a cross section taken at line 2—2 in Fig. 1;

Figs. 3, 4 and 5 are cross sections similar to Fig. 2 showing sequential steps in the installation of the detent;

Fig. 6 is an end view showing another embodiment of the invention;

Fig. 7 is a bottom view of the presently preferred embodiment of the invention;

Fig. 8 is a top view of the presently preferred embodiment of the invention;

Fig. 9 is a fragmentary view taken at line 9—9 in Fig. 6;

Fig. 10 is a side view of the initial shape of the retention spring of Figs. 6 and 9;

Fig. 11 is a cross-section taken at line 11—11 in Fig. 10;

Fig. 12 is a view similar to Fig. 9 showing a variation thereof;

Figs. 13 and 14 show variations of basic unreformed retention spring shapes;

Figs. 15 and 16 show two sequential steps accomplished by preferred tooling;

Fig. 17 is a fragmentary axial cross-section showing optional detents; and

Fig. 18 is a fragmentary transverse cross-section showing other optional detents.

Fig. 1 shows a motor housing 10 which constitutes an important use for the instant invention. Such a housing includes a steel motor ring 11 which may be formed as a seamless tubing, or as a tubing formed with a seam. It has an outer wall 12, an inner wall 13, and a central axis 14. The inner wall is circularly curved.

It is customary for these motor rings to have attached to them a pair of permanent magnets 15, 16. Usually these are ceramic. The magnets have an inner surface 17 and an outer surface 18 whose curvature is the same as the inner wall, both being centered on the axis. The magnets include abutment surfaces 19, 20, 21, 22, one pair on each magnet. One face of each magnet faces another face on the other magnet. One of the objects of this invention is firmly to hold the so they do not slide along it or fall away from it. It is to be remembered that ceramic magnets are often quite brittle, and it is necessary that forces exerted on them not be exerted in such a manner or at such intensities as are likely to cause fracture of the magnet.

A retention spring 25 according to this invention is provided for holding the magnets in place. Magnets are given as an example of a use of this invention, and not as a limitation on the utility of invention. The initial, unreformed shape is best shown in Figs. 3, 7 and 8. The retention spring is made of a metal such as carbon steel which has classic elastic stress-strain properties at lesser stresses, and an elastic limit above which permanent deformation occurs when greater stress is applied. This is to say that it inherently has a substantial spring-loaded capacity, and also that it can be permanently deformed.

The retention spring includes a pair of arms 26, 27 (Fig. 3) joined by an integral central apex or bight 28 which comprises a bend between the arms, thereby forming a dihedral angle between them. A convenient, and the presently-preferred shape of the arms between their connecting bight and the points of contact with the next assembly, for example with the magnets and with the inside wall of the ring, is a substantially straight segment. In many preferred applications, at the free ends (the ends most distant from the apex or bight) both of the arms have a curvilinear surface 29, 30, respectively.

Surfaces 29 and 30 are formed as a curl in the metal. The metal is preferably slotted by slots 31, 32 to form a plurality of fingers 33, 34. These slots and fingers serve to distribute the pressure against the hard and potentially uneven surfaces of the magnet. However, the slots and fingers are optional depending on the unit forces to be applied by the curvilinear surface.

Significant design and construction features at the ends of the detent arms (whether they curl up or down, whether instead of curling during installation they are configured to bend to take up tolerance variations, whether they are simple arm extensions bowed into the magnet surfaces, and/or whether, and is so how the ends are slotted to adapt to uneven surfaces) are all pragmatic matters and will be determined by normal design and tests for optimum performance in each application. Persons skilled in the art will have no difficulty in designing correct configurations and dimensions for their individual installations. Suitable dimensions and specifications for a typical retainer spring to install in an inner wall with a diameter about $2\frac{7}{8}$" diameter, permanent magnets about $\frac{3}{8}$" thick and spaced apart at their ends by approximately 1" to 1 3/16" at their inner surfaces are as follows: stock thickness .030"; stock width $1\frac{1}{4}$"; spring height preformed .55"; spring height final formed (reformed) .25"; spring length preformed .95"; spring length final formed: without restraints $1\frac{1}{4}$"; with restraints 1" to 1 3/16". A suitable material ...

The installation of this device requires permanent deformation of the body in such a way as to increase the spacing apart of the outer ends of the arms absent restraint ("intrinsic length"). Of course, the abutment surfaces are normally essentially immovable and therefore they do constitute a restraint.

One of the problems of spring retainers is that a high retention force requires a stiff, high-rate spring which is very sensitive to dimensional tolerances. In order for such a spring to exert a suitable separative force, it ordinarily must itself be compressed and allowed to spring back against the abutment surfaces. Also, the effective spring force is quite sensitive to the spacing between the abutment faces and to the accuracy of the dimension of the spring itself. It should also be remembered that in permanent magnet motor assemblies an increase of spacing between one pair of adjacent abutment faces decreases the spacing between the other pair, so that one spring might be installed too tightly and another one too loosely. An advantage of this invention is that it enables the springs to be formed in place and stressed correctly in accordance with the actual existing, not a theoretical, spacing between the abutment faces.

The magnets are installed while holding them as closely to a symmetrical installation as is reasonably possible along with the use of high rate assembly tooling. A pair of lower anvils 40, 41 are located axially along the inner wall, and have forming surfaces 42, 43, respectively, which are flat (Figs. 3—5) or slightly concave (see Figs. 14 and 15). A pair of upper anvils 44, 45 are provided to move radially as shown by arrows 46 in Fig. 4, and preferably will have a convex surface. The terms "upper" and "lower" for convenience relate only to the side of the spring the respective anvil is placed on. The relationship to the vertical is not material.

A retention spring is placed between each of the facing abutment surfaces, and it will be noted that there can be, and usually there will be, a loose fit. The retention spring need not be compressed in order to set it between the abutment faces. Most conveniently, it will be inserted from the end, and need not clear inner corners 47, 48. In any event, it can form a loose fit relative to its adjacent abutment faces, thereby illustrating the feedom of this device from close tolerance constraints in the course of assembly.

In the next step of installation, the anvils are moved to contact the center of the retainer apex or bight, and this forces the fingers outwardly and sidewardly so as to contact both the inner wall of the ring and the respective abutment face. This takes up the tolerances in the system. The anvils continue to move the retainer apexes toward, but not beyond lines drawn between the points of contact with the abutment surfaces. This further movement causes the arms to bow, i.e., b nd convexly away from the wall of the ring. This bowing deformation is at least partially temporary even though some permanent deformation also results. Thus, even though the retention spring has at this stage been deflected to take up tolerances and apply load to the magnets and ring assembly, if it were released there would be substantial spring back, and an optimally reliable assembly would not be produced. To avoid spring back and to assure maximum retention forces on the magnet assembly, the final spring reforming stage is a permanent re-working of a localized region or regions which has the effect of reversing or opening the bow curvature and thus increasing the lateral spring load.

The initial spread of the arms, and the bowing action is shown in Fig. 4. Because of the properties of the metal, the angular bight or apex in this configuration does not simply open like a book. Instead, the arms spread and bow slightly and after taking up clearances, the fingers yi ld as necessary to relieve excessive localized forces on the abutting surfaces. A "peak" 28a, which is exaggerated in Fig. 4 remains. Even if not so pronounced, it still is a raised, rounded local region. When anvils 44 and 45 finally close they rework and permanently change the curvature of the bight in the localized area, so as to cause the dihedral angle between the arms to increase, this further bowing the balance of the length of arms — causing bending stresses at least close to, and preferably beyond the yield point. The increases in the bow stresses of the arms increases the separative forces at the ends of the arms.

This reformation in place has occurred *after* the retention spring has taken up the tolerances and received an initial bowing spring tension. However variable they may have been, there is enough movement left as the consequence of the final permanent deformation to provide in a given retainer structure close to maximum separative forces irrespective of relatively large variations in assembled length. Spring-back unloading is slight because it is limited to the small portion of the bow retainer which is re-worked between anvils 44 and 45. Thus, a reliable and suitable predictable spring load is generated in the retention spring *after* it is placed in its working position.

The rather easier bending of the fingers permits readier adaptation of shape of the permanently deformed detent over a broader range of tolerances of parts and their installation. It is evident that the force exerted by the inner anvil has caused a permanent deformation by virtue of having stressed the metal at a stress level in excess of its elastic limit. Fig. 4 illustrates that the geometry of the anvil surfaces and of the bight is such that a change of shape in the s nse of changing the bend can readily occur.

The anvils are now s parated and the tool ass mbly slid out — the slight spring-back of the retention spring permitting ready removal of the tools.

It will be observed that this installation has

between upper and lower anvils creating a retention system which is entirely related to each specific installation rather than to theoretical dimensions.

There are important possible variations to the simplest embodiment shown in Figs. 1—5, 7 and 8. For example, a retention spring 70 is shown in Fig. 13 which has all of the features and the same general construction as retention spring 25. It differs in that its bight 71 has a rounded apex 72 which makes more pronounced the spreading and bowing of the arms 73, 74 when the apex is flattened against the anvil.

Fig. 14 shows a retention spring 80 whose bight 81 is more complex. It has a dimension of width, and includes two apexes 82, 83 similar to apex 72. This construction is useful when longer separations are to be spanned. Two sets of anvils are used, one for each of the apexes. Apart from the plurality of apexes, and differences in dimensions retention spring 80 is in all respects similar to spring 25.

Figs. 15 and 16 show preferred tooling. A moving upper anvil 90 and fixed lower anvil 91 are provided as before. However anvil 90 has a curved nose 92, and anvil 91 has a concave forming face 93 with a recessed central portion 94 and a peak 95, 96 on each side of it. Fig. 15 shows the tooling at the end of the first step — it has expanded the retention spring to take up the tolerances and made the initial bowing.

Fig. 16 shows the final step, and here the moving anvil has travelled the full distance and formed in a limited length of the bow a concave shape 97 at the bight. Thus, the central region has had an even more profound change of curvature to spread the arms than if the lower anvil were flat.

Centering notches 99 are optionally formed in the edges of the bight. These or other provisions such as a single hole can be engaged by tooling to hold the spring centered during the setting so as not to drift off excessively to one side or the other.

Figs. 6 and 9—12 illustrate that the bight of the retainer spring need not extend axially along the wall of the ring, but instead can be normal to it. Otherwise stated, a plane cut normally through the bight and both arms lies along the wall, rather than normal to the wall.

In Fig. 6, two retainer springs 100, 101 are shown interposed between magnets 102, 103, bearing against abutment faces 104, 105, 106 and 107. They also bear against the inside wall 108 of the steel ring 109. The detailed construction of these identical retainer springs is best shown in Figs. 9—11.

In Fig. 9, spring 100 is shown with a central bight 110 and two arms 111, 111a. The spring is formed from wire or rod. As best shown in Fig. 11, it has generally rounded corners, and an outer straight face 112 (contact surface) that bears against the abutment surface. The initial shape of the spring is shown in Fig. 10, where the bight can be initially flat or rounded upward as previously pressed against it, it will tend to remain centered, rather than to drift to one side. However, a somewhat rounded or even peaked bight will perform satisfactorily. The legs are spread apart by a nominal distance which will enable the spring to be placed between the abutment surfaces with ease. Then the retainer spring is reworked between anvils in a limited portion of its working length, as previously described, to reverse the bow curvature and cause the arms to spread apart, take up the tolerances, and stress-load the bow. Tooling similar to that shown in Figs. 15 and 16 can be used. The most advantageous technique is to form a reverse curve 113 in the bight as shown. Alternatively, the bight could have been made with an initial convex shape, and been flattened when the spring was reformed in place.

Fig. 12 shows a retention spring 120 which is essentially a combination of two of the springs shown in Figs. 9—11. It has a pair of bights 121, 122, and each bight connects a pair of arms as before. However, two of the arms are connected. The setting of this spring is identical to that of the embodiment of Fig. 9, except that two sets of tooling are used simultaneously.

Fig. 17 shows additional means to secure the assembly against unusual shock loads which might be experienced in shipping or abnormal use. A tube 200 within inner wall 201 receives a pair of magnets 202, 203 as in the other embodiments. The tube has a central axis 204. A retention spring 205 according to any of the embodiments is installed between two magnets. Detents to restrict any vibrating or shock displacements of magnets, for example detents 206, 207 may be located on the inside wall of the tube. These may be metal, and may constitute raised stud-like structures, which can be located where either or both of the ends of the magnets are to be located. Any desired number of detents can be provided, and if preferred, the detents could instead be ring-like structures.

For some installations, it is sufficient to use only one retention spring. An example is shown in Fig. 18, where tube 210 with an inner wall 211 has magnets 212, 213 held in it by means of retention spring 214. Spring 214 can be according to any of the embodiments disclosed herein. The abutting surfaces 215, 216 away from spring 214 must, of course, be restrained. A spacer (not shown) could be placed in abutment with these surfaces, or instead: detents 217, 218 may be formed on the inner wall to be borne against by the magnets. As in Fig. 17, the detents could be created by deformation of the metal by a force exerted on the outer wall of the tube.

In summary, in all embodiments, a retention spring is made from reformable resili nt metal into a bow or a wave-type structure with arms at each end to contact and oppose abutment surfaces on articles to be retained. The spring has a bight with one or more apex portions at a location off of (above) the load contact points, and also above

The installation procedure involves three sequential operations:

a. Reducing the height of the spring with the concomitant extension of the arms to take up assembly clearances. This may be accomplished initially by causing the arms to slide along a surface such as the inside wall of the ring, or solely by spreading the arms by reversing the curvature in a limited bight or apex portion of the spring.

b. Further reducing the height and/or reversing the bight curvature to provide a bowing deformation (which may be permanent) to spring-load the arms against the abutment surfaces. This is a continuation of step a, above, and can result in random bending of the arms, more closely controlled bending if the geometry is designed for it, or a curling of portions designed for the purpose such as the fingers in Figs. 1—5.

c. The final reworking of a limited apex region, which permanently deforms that region to change its curvature, and increase the bow curvature and stress in the arms.

It is further to be observed that, instead of retaining two articles with the use of the two retainer springs, each of the retainer springs bearing against two articles, one of the abutment surfaces could be on fixed structure instead and only one article retained. Furthermore, permanent detents can be used in lieu of one of the retention springs.

The term "intrinsic length" is sometimes used herein. This term is meant to describe what would be the length of the retention spring (i.e., the spacing between its contact points) absent restraint. This is not the first extension where the spring is deflected to take up the assembly clearances. Instead it is the consequence of the further bowing of the arms, and of the permanent reformation in the limited area in the bight. This intrinsic increase in length, is never actually realized by the spring retainer, because its extension is resisted by the abutment surfaces, causing the arms to become bowed and to store energy. Thus when the reworking forces are removed, the spring-back energy losses are limited to that relatively small portion of its working length which was reworked to reverse the bow curvature. The retainer is quickly and efficiently set in place with its ultimate configuration and maximum loading irrespective of varying assembly tolerances.

This invention is not to be limited by the embodiments shown in the drawings and described in the description, which are given by way of example and not of limitation, but only in accordance with the scope of the appended claims.

CLAIMS

1. A retention spring biasing an article to hold it in place, said article having an abutment surface facing toward and being contacted by said spring, said spring also bearing against a second having a contact surface, whereby spaced-apart portions of each arm make contact with a respective abutment surface, and a bight connecting said arms, the metal of said body providing significant spring loading capacity, and permitting of permanent deformation, said bight, after placement of said retention spring between said abutment surfaces, having been locally permanently deformed by stress exerted in such a way as would, absent restraint by said abutment surfaces, enlarge the intrinsic length of said retention spring, the arms thereby being bowed and storing energy which exerts a force against said abutment surfaces.

2. A retention spring according to claim 1 in which said article has a curved surface, and is being biased by said spring to hold said article against sliding movement along a similarly curved wall as a consequence of frictional resistance.

3. A retention spring according to claim 2 in which said bight and arms have a substantial width, said contact surfaces being disposed near the face ends of said arms.

4. A retention spring according to claim 3 in which said arms are curled adjacent to their ends.

5. A retention spring according to claim 4 in which slots are formed in said curled portions to form fingers.

6. A retention spring according to claim 2 in which a centering notch is formed at each edge of said bight.

7. A retention spring according to claim 2 in which said contact surfaces are disposed on the arms at a location spaced from said free ends, and in which said bight and said arms are all adjacent to said wall.

8. A retention spring according to claim 7 in which the curvature of said bight has been permanently changed by deformation of the material thereof.

9. A retention spring according to claim 2 in which said bight is disposed on the opposite side of a line down between the points of contact with the abutment surfaces, from said wall.

10. In combination at least one retention spring according to claim 2, a rigid tubular ring having said similarly curved wall as a cylinder; and a plurality of said curved articles, each bearing one of said abutment surfaces.

11. A combination according to claim 10 in which said bight and arms have a substantial width, said contact surfaces being disposed near the face ends of said arms.

12. A combination according to claim 10 in which said contact surfaces are disposed on the arms at a location spaced from said free ends, and in which said bight and said arms are all adjacent to said wall.

13. A retention spring for exerting a separative force between two adjacent, spaced-apart abutment surfaces, said spring comprising a metal body having a pair of spaced-apart arms, each arm having a contact surface, and a bight connecting

of permanent deformation.

14. A retention spring according to claim 13 in which the bight has a substantial width, and the contact surfaces are curved and located adjacent to the free ends of said arms.

15. A retention spring according to claim 14 in which the contact surfaces are slotted whereby to be formed on fingers.

16. A retention spring according to claim 14 in which an apex is formed on said bight as a convex bend arising therefrom.

17. A retention spring according to claim 13 in which the bight has a substantial dimension between said arms.

18. The method of installing a retention spring between two opposed abutment surfaces so the spring exerts a separative force against said abutment surfaces, said surface being spaced apart by a spacing and lying adjacent to a wall, said retainer spring comprising a sheet-like springy metal body having two arms with contact surfaces to bear against respective ones of said abutment surfaces, and a bight between and joining said arms which is substantially displaced from a line extending between said contact surfaces, and the distance between said contact being initially shorter than said spacing, said method comprising: placing said retention spring between said abutment surfaces, and as a first step, pressing on said bight so as to extend the actual length of said retention spring to occupy said spacing, as a second step, continuing to press on said bight so as to enlarge the intrinsic length of said retention spring and thereby bow said arms, and as a third step, permanently to reform a limited portion of said bight so as to change its curvature in a manner which will additionally increase said intrinsic length.

19. A method according to claim 18 in which the free ends of said arms are also pressed against said wall.

20. A method according to claim 18 in which said body initially has a convex apex in said limited portion, whose curvature is reduced in said reformation.

21. A method according to claim 18 in which said third step is accomplished by pressing said limited portion in a tool having curved forming faces.

22. A method according to claim 18 in which the free ends of the arms are initially curled, whereby during said second step they are additionally curled to take up tolerances.

23. A method according to claim 18 in which the free end of the arms are initially bent, whereby during said second step they are additionally bent to take up tolerances.

24. A retention spring according to claim 3 in which said arms are bent adjacent to their ends.

25. A retention spring according to claim 24 in which slots are formed in said bent portions to form fingers.

26. A retention spring substantially as hereinbefore described with reference to the accompanying drawings.

27. A method of installing a retention spring, substantially as hereinbefore described with reference to the accompanying drawings.

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